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Experimental Analysis of Generating Power from Mechanical Stress Kinetic Energy (Footsteps or Vehicle Pressure)

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Abstract

This research paper investigates the generation of electrical energy from mechanical stress, especially from footsteps and vehicle pressure, using piezoelectric transducers. The main objective is to experimentally analyze how force, repeated loading, arrangement of sensors, and electrical conditioning circuits influence the voltage and current output of the system. The project is relevant because large amounts of mechanical energy are wasted daily in crowded locations such as railway stations, shopping malls, footpaths, parking areas, toll plazas, and roads.

The report discusses the physical principle of piezoelectricity, the design of a prototype system, the bridge rectifier and storage circuit, data collection methods, and performance evaluation. It also compares practical limitations such as small output power, dependency on intermittent loading, durability issues, and conversion losses. Along with experimental observations, the project presents tables, calculations, graphs to be drawn manually if needed, applications, future scope, and safety aspects. The report concludes that piezoelectric mechanical energy harvesting is feasible for low-power applications like LEDs, sensors, counters, and wireless monitoring systems, but it is not yet suitable for large-scale bulk power generation without significant optimization.

Keywords: Piezoelectricity, Piezoelectric Transducers, Energy Harvesting (or Mechanical Energy Harvesting), Piezoelectric Sensors, Electrical Conditioning Circuits, Bridge Rectifier, Energy Storage Circuits, Low-Power Applications, Voltage and Current Output, Mechanical Stress, Dynamic Loading (or Repeated Loading), Transducer Arrangement (or Array Optimization), Conversion Efficiency (or Conversion Losses), Smart Infrastructure, Footstep Power Generation, Vehicle Pressure Harvesting, Renewable Energy Sources.

1. Introduction: In an era defined by rapid urbanization and escalating energy demands, the quest for sustainable and clean energy sources has transitioned from a futuristic ideal to an immediate global necessity. While traditional renewable energy technologies like solar and wind power continue to mature, they are inherently dependent on environmental conditions and geographical locations. Concurrently, a massive, ubiquitous source of energy remains largely untapped: ambient mechanical energy generated by human and vehicular motion.

Every day, millions of people walk through transit hubs, and countless vehicles traverse highways, exerting immense mechanical force onto the ground. This kinetic energy is typically dissipated into the environment as ambient noise, vibration, and heat. Harvesting this wasted mechanical stress and converting it into usable electrical energy represents a paradigm shift toward localized, decentralized micro-generation.

1.1 The Mechanism: Piezoelectricity and Electromagnetic Induction: The mechanical stress exerted by footsteps or passing vehicles can be harvested primarily through two prominent technologies: **piezoelectric transduction** and **electromagnetic induction**.

- **Piezoelectric Systems:** Certain materials possess a unique atomic structure that generates an electric charge when subjected to mechanical deformation. When a footstep or vehicle tyre compresses a piezoelectric element, it shifts the internal dipole moments, creating a potential difference (voltage) across the material.
- **Electromagnetic Systems:** Alternatively, mechanical pressure can compress a spring-loaded mechanical assembly, forcing a permanent magnet through a coil of wire. According to Faraday's Law of Induction, this relative motion alters the magnetic flux, inducing an electrical current.

1.3 Problem Statement: Urban infrastructure is a hotbed of dense kinetic activity, yet this energy is continuously lost. Standard power grids rely heavily on centralized fossil-fuel generation, incurring transmission losses and heavy carbon footprints. While low-power electronics, smart streetlights, and localized IoT sensors are proliferating in urban spaces, powering them requires continuous grid dependency or frequent battery replacements.

There is a critical need to design, prototype, and rigorously analyze an efficient, scalable system capable of capturing high-frequency, low-amplitude mechanical impulses (such as foot traffic or vehicular pressure) and converting them into regulated, storable electrical energy.

1.1.1. Research Objectives: The primary objectives of this research project are:

1. **Design and Fabrication:** To develop a functional prototype of a kinetic energy-harvesting platform (tile or speed breaker mechanism) utilizing optimized transducer elements.
2. **Performance Evaluation:** To experimentally analyze the relationship between varying input masses (different human weights or vehicle types), frequency of impacts, and the resulting electrical output (voltage, current, and power).
3. **Power Conditioning Analysis:** To engineer and test an efficient power management circuit (rectifiers, step-up converters, and storage units like supercapacitors or lithium-ion batteries) to convert erratic AC spikes into a stable DC output.
4. **Feasibility Study:** To evaluate the scalability and cost-effectiveness of deploying these energy-harvesting modules in high-traffic zones like railway stations, malls, or toll plazas.

1.5 Significance of the Study: This research contributes to the development of self-sustaining "Smart Cities" by providing a blueprint for grid-independent localized power. By capturing energy that is otherwise entirely wasted, this technology offers a clean, localized power solution for small-scale applications such as emergency lighting, pedestrian signaling, and wireless sensor networks. Ultimately, this study bridges the gap between theoretical solid-state physics and practical, green engineering solutions for the modern world.

1.6 The Central Hypothesis: If a power generation system utilizing piezoelectric transducers or electromagnetic induction is subjected to recurring mechanical stress from human footsteps or vehicle pressure, then it will convert a measurable percentage of that kinetic energy into usable electrical energy, because the applied mechanical deformation directly forces a shift in dipole moments (piezoelectric) or cuts magnetic flux lines (electromagnetic), inducing a voltage.

1.7 Specific Hypotheses for Experimental Testing: To make your research rigorous, you can break your central hypothesis down into primary and secondary directional hypotheses:

1.1.2. 1. The Core Relationship (Primary Hypothesis)

- **Alternative Hypothesis (H_1):** There is a statistically significant positive correlation between the amount of mechanical force (weight/frequency of footsteps or vehicles) applied to the energy-harvesting platform and the amount of electrical power generated.
- **Null Hypothesis (H_0):** The mechanical force applied to the platform has no significant effect on the electrical power generated, and any variation is due to random error.

1.1.3. 1.7.2.. Efficiency & Impact Variables (Secondary Hypotheses)

- **Hypothesis on Vehicle vs. Human Footsteps:** Vehicle pressure will yield a significantly higher peak voltage output per impact compared to human footsteps, but will require more robust materials to prevent mechanical failure and energy dissipation.
- **Hypothesis on Frequency/Traffic Density:** An increase in the frequency of impacts (simulating high-traffic areas) will lead to a linear increase in total accumulated energy (Watt-hours) over time, provided the system has an optimal rectification and storage circuit.

Defining Variables: To ensure your hypothesis is testable, your experiment should isolate and measure the following:

- **Independent Variable(s):** * The magnitude of mechanical stress (e.g., weight of individuals: 60kg vs. 90kg, or vehicle classes: cars vs. motorcycles).
  - The frequency of impacts (e.g., 10 steps/minute vs. 60 steps/minute).
- **Dependent Variable(s):** * Electrical output (measured in Voltage V, Current mA, and Power mW).
  - Total energy accumulated over a set duration (Joules or Watt-hours).
- **Control Variables:** * The surface area of the impact platform.
  - The type and arrangement of transducers used (e.g., PZT piezoelectric ceramic discs in a series-parallel circuit).
  - Environmental conditions (temperature, moisture).

1.2. Objectives of the Project

- To understand the piezoelectric effect and its role in energy harvesting.
- To design and assemble a prototype system that converts footstep or pressure input into electrical output.
- To measure output voltage under different loading conditions.
- To compare the effect of single and multiple piezoelectric sensors connected in various combinations.
- To study the role of a rectifier, capacitor, and storage element in improving usable output.
- To evaluate the practical feasibility of the system for real-world low-power applications.
- Choosing suitable components and methods based on the configurations availability and requirements.

- Testing and remedies

1.3. Renewable Energy Overview

Renewable Energy refers to energy obtained from natural sources that are continuously replenished and do not get exhausted easily. These sources are environmentally friendly and help reduce pollution and dependence on fossil fuels.

Examples include.

Importance of Renewable Energy -

- Reduces environmental pollution
- Conserves fossil fuels
- Helps control climate change
- Supports sustainable development

Common renewable energy sources include

1. Solar Energy
2. Wind Energy
3. Hydropower Energy
4. Biomass energy
5. Geothermal Energy

3.1 Solar Energy -Solar energy is produced using sunlight. Solar panels convert sunlight into electrical energy.

Applications:

1. Home electricity
2. Street lighting
3. Water heating
4. Solar irrigation pumps

Advantages:

1. Eco-friendly
2. Renewable source
3. Low operating cost

Disadvantages:

1. Depends on sunlight
2. High installation cost

3.2 Wind Energy -Wind energy is generated by using wind turbines that convert wind motion into electricity.

Applications:

1. Power generation

2. Water pumping systems

Advantages:

1. Clean and renewable
2. No fuel required

Disadvantages:

1. Depends on wind availability
2. Can produce noise

1.4. Hydropower Energy -

Hydropower uses flowing water to generate electricity.

1. Applications:

1. Large-scale power production

2. Advantages:

1. Reliable and efficient
2. Long operational life

3. Disadvantages:

1. Expensive construction
2. Environmental impact on rivers

3.1. Biomass Energy -

Biomass energy is generated from organic materials such as agricultural waste, wood, and animal waste.

4. Applications:

1. Cooking fuel
2. Electricity production
3. Biofuel manufacturing

Advantages:

1. Utilizes waste materials
2. Renewable resource

5. Disadvantages:

1. Air pollution possible
2. Requires large biomass supply

5.1. Geothermal Energy

Geothermal energy uses heat from inside the Earth to generate power.

6. Applications:

1. Power plants
2. Heating systems

7. Advantages:

1. Reliable energy
2. Environment friendly

8. Disadvantages:

1. Available only in specific regions
2. Expensive installation

4. Kinetic Energy: The kinetic energy of an object is the energy that it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity. Having gained this energy during its acceleration, the body maintains this kinetic energy unless its speed changes. The same amount of work is done by the body when decelerating from its current speed to a state of rest. Formally, a kinetic energy is any term in a system's Lagrangian which includes a derivative with respect to time.

In classical mechanics, the kinetic energy of a non- rotating object of mass m traveling at a speed v is 1/2 mv In relativistic mechanics, this is a good approximation only when v is much less than the speed of light.

The standard unit of kinetic energy is the joule, while the English unit of kinetic energy is the foot-pound.

- **Energy:** The capacity to do work is called Energy. This energy can be stored in different forms. Energy is one of the physical quantities as it is proportional to the mass of the object. The ability of the body to exert a push or a pull against natural forces like gravity identifies what kind of energy it is. When an object is at rest, the body is said to possess potential energy. In another case, when the object is in motion, then it is said to possess kinetic energy.
- **Potential Energy: Potential energy** is the energy held by an object because of its position relative to other objects, stresses within itself, its electric charge, or other factors.

Common types of potential energy include the gravitational potential energy of an object, the elastic potential energy of an extended spring, and the electric potential energy of an electric charge in an electric field. The unit for energy in the International System of Units (SI) is the joule, which has the symbol J.

The term potential energy was introduced by the 19th- century Scottish engineer and physicist William Rankine , although it has links to Greek philosopher Aristotle's concept of potentiality. Potential energy is associated with forces that act on a body in a way that the total work done by these forces on the body depends only on the initial and final positions of the body in space. These forces, that are called conservative forces, can be represented at every point in space by vectors expressed as gradients of a certain scalar function called potential.

Since the work of potential forces acting on a body that moves from a start to an end position is determined only by these two positions, and does not depend on the trajectory of the body, there is a function known

as potential that can be evaluated at the two positions to determine this work.

There are various types of potential energy, each associated with a particular type of force.

What Is Kinetic Energy and Potential Energy Formula?

Potential energy and kinetic energy are both measured in joules (J), named after the English mathematician, James Prescott Joule. But they have different formulas with respect to their different attributes. Potential energy depends on the force acting on the two objects, so its formula is:

Potential Energy = mgh

- **m** is the mass measured in kilograms
- **g** is the acceleration due to gravity
- **h** is the height in meters

Kinetic energy is directly proportional to an object's mass and the square of its velocity. Putting it in a formula we get:

Kinetic Energy = 1/2 m v^2

- **m** is the mass measured in kilograms
- **v** is the velocity of meters per second

5. Study piezoelectric effect : India and many other countries face increasing energy demand. Although large-scale energy is commonly generated by thermal, hydro, nuclear, and solar plants, there is also a growing need for decentralized low-power sources. Crowded urban infrastructure contains many forms of wasted energy. Footstep pressure is one such source. If harvested effectively, it can power LEDs, counters, digital displays, sensors, wireless nodes, or emergency lighting in public spaces. The study is important because it helps students understand the gap between a clever concept and practical engineering reality. Even if the power obtained is small, the project demonstrates sustainability, efficiency analysis, and experimental validation. This research therefore has educational, environmental, and technological importance.

8.1. The Core Physics: How It Works

The **piezoelectric effect** is the ability of certain materials to generate an electric charge in response to applied mechanical stress.

Mechanical Stress (Footstep/Vehicle) ➔ Lattice Deformation ➔ Electric Polarization ➔ Voltage Output

When pressure is applied to a piezoelectric material, its internal crystalline structure deforms. This displacement of ions creates a net dipole moment, resulting in an electric potential (voltage) across the material's faces. Because this occurs under dynamic loading, the output is alternating current (AC) and fluctuates with every step or tire impact. Key Material Selections

- **PZT (Lead Zirconate Titanate):** A piezoceramic. It has a high piezoelectric coupling coefficient, meaning it is highly efficient at converting stress to electricity. However, it is brittle and prone to cracking under high impact.

- **PVDF (Polyvinylidene Fluoride):** A piezo-polymer. It is highly flexible and durable, making it excellent for footstep mats, though its energy conversion efficiency is lower than PZT.

8.2. Experimental Setup & System Architecture

To analyze this system, you need to build a structural prototype (the energy harvester) and a power conditioning circuit.

8.2.1. A. The Mechanical Transducer Platform

- **Footstep Tile:** Design a spring-loaded or cantilever mechanism. Piezoelectric elements yield higher output under bending/strain rather than pure compression. Placing PZT discs on a flexible substrate that flexes slightly when stepped on optimizes voltage yield.
- **Array Configuration:** Connect multiple piezo elements.
  - **Series connection** increases the output voltage.
  - **Parallel connection** increases the output current (usually preferred since piezo elements naturally have high voltage but incredibly low current).

8.2.2. B. The Power Conditioning Circuit

The raw electricity generated by a footstep is a high-voltage, low-current AC spike. It cannot charge a battery directly. You need a conditioning circuit:

1. **Full-Wave Bridge Rectifier:** Converts the AC spikes into Direct Current (DC). Fast-switching diodes (like 1N4148 or Schottky diodes) are required because standard diodes drop too much voltage and are too slow for transient piezo spikes.
2. **Filtering Capacitor:** Smooths out the pulsed DC into a steadier voltage.
3. **Buck Converter / Voltage Regulator:** Regulates the high voltage down to a usable level (e.g., 5V or 3.3V).
4. **Storage Element:** A Li-ion battery or a Supercapacitor to store the harvested energy.

8.3. Experimental Analysis & Variables to Measure

To make this a robust research project, your analysis should quantitatively measure how different variables impact power yield.

8.3.1. Key Parameters to Monitor

- **Open-Circuit Voltage (V_{oc}):** Peak voltage produced by the piezo element before it is connected to a load.
- **Short-Circuit Current (I_{sc}):** Maximum current capability.
- **Power Output (P):** Calculated using $P = V \times I$ across different load resistors to find the optimum impedance match.

8.3.2. Variables to Test (The "Analysis" Component)

1. **Impact Force vs. Energy Yield:** Use varying weights (e.g., 50 kg, 70 kg, 90 kg to simulate different people, or heavier loads for vehicle simulation) and measure the peak power generated.

2. **Frequency of Impacts:** Measure the performance of the system when subjected to rapid footsteps (running) versus isolated impacts (walking).
3. **Circuit Efficiency:** Compare the raw energy produced by the piezo element against the actual energy stored in the capacitor to evaluate the loss in your rectification circ

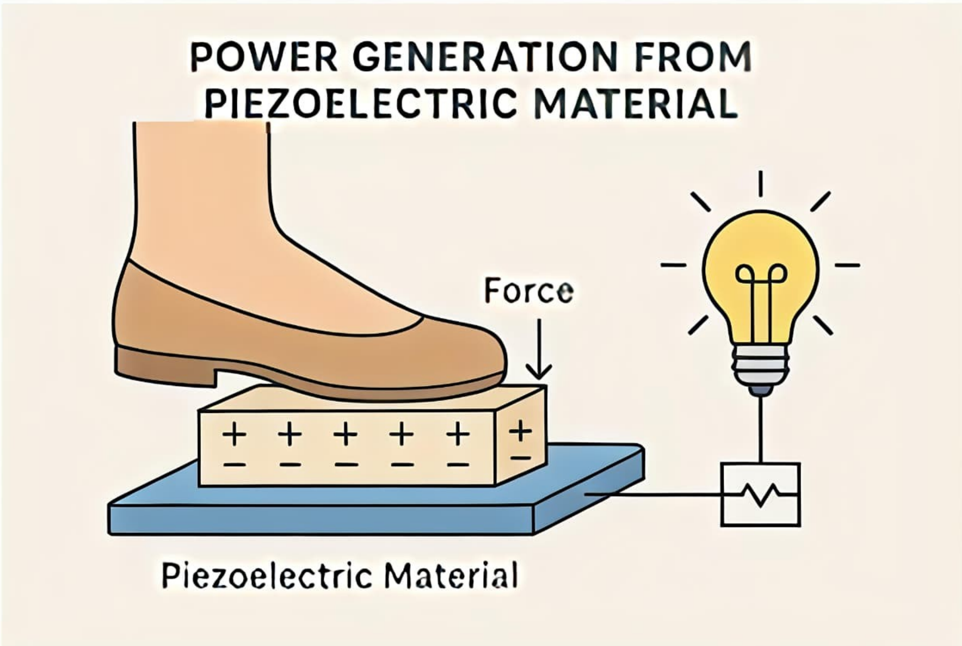

Figure : power Generation from Piezoelectric Material

8.4. The principle of the Piezoelectric Effect -

The piezoelectric effect is the ability of certain crystalline or ceramic materials to produce electric charge when they are mechanically deformed. The word comes from the Greek word “piezein,” which means “to press.”

There are two forms of this effect. The direct piezoelectric effect converts stress into electricity, while the inverse piezoelectric effect converts electricity into mechanical deformation. In this project, the direct effect is used.

Common piezoelectric materials include quartz, Rochelle salt, PZT (lead zirconate titanate), PVDF films, and engineered ceramic discs. Among these, PZT is commonly used in student projects due to its strong response and easy availability.

The generated charge depends on material properties, force direction, electrode area, and deformation amount.

5.2 Working Principle of the Proposed System: In the prototype, piezo discs are fixed under a plate made of plywood, acrylic sheet, or metal support. When a person steps on the plate, the plate bends slightly and compresses the sensors. Each piezo element generates a voltage pulse. Multiple elements may be connected in series for higher voltage or in parallel for higher current. The output is then sent to a bridge rectifier to convert it into DC pulses. After rectification, a capacitor stores charge and smooths fluctuations. The stored energy can be used to light an LED, charge a supercapacitor, or provide short bursts to a small load. For vehicle pressure applications, the same concept is enlarged into a robust pad placed under a tire contact area or speed breaker type module. Footsteps Energy Generation.

6. FOOT STEP ARRANGEMENT : This is made up of mild steel. The complete set up is fixed in this model FOOT STEP.

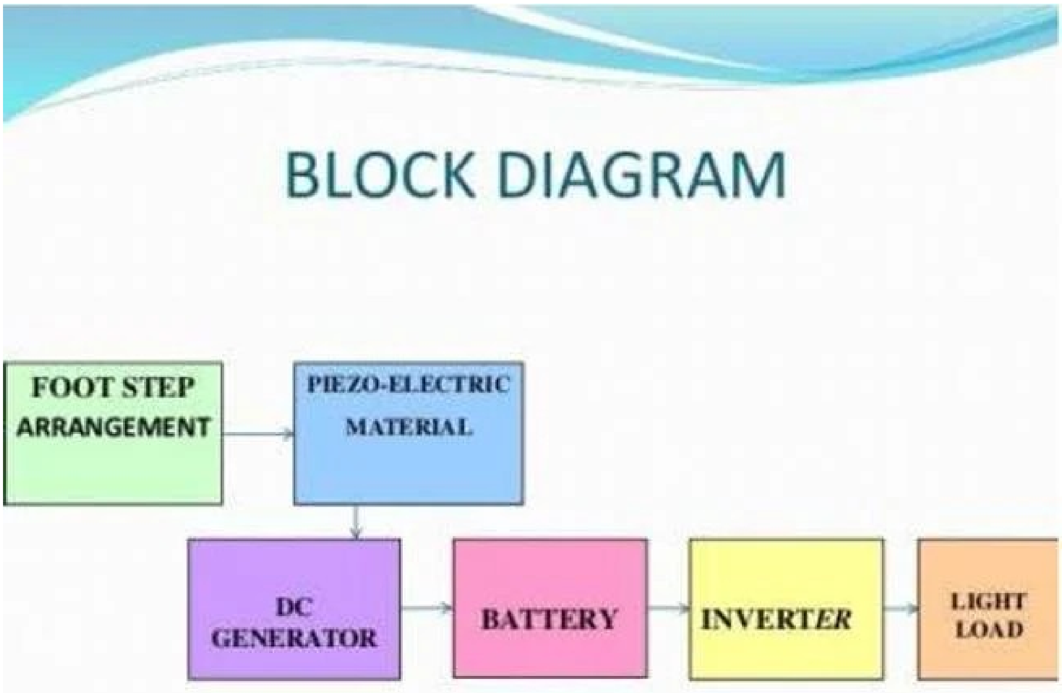

Figure : Block Diagram

The two L-shapes frame is fixed in the above two ends of the track. Bellow this l-shapes window, the actual power generation arrangement is constructed. This L-shapes window pushes the rack when the time of train wheel moving on these arrangement.Footstep energy generation uses human walking pressure.

9. When a person walks over the pressure plate:

- Force compresses piezoelectric sensors.
- Electrical energy is produced.

- Energy is collected and stored.

10. Advantages -

- Easy installation
- Eco-friendly
- Useful in crowded places

11. Applications -

1. Railway stations
2. Airports
3. Schools
4. Malls

11.1. Mechanical Assembly of Footstep Tile -

A square plate of approximately 25 cm × 25 cm can be used for a student model. Below the plate, piezo discs are arranged symmetrically. Rubber pads or foam pieces help distribute the load and prevent sudden impact. The tile should be rigid enough for stepping but flexible enough to create slight deformation. Proper assembly directly affects output.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

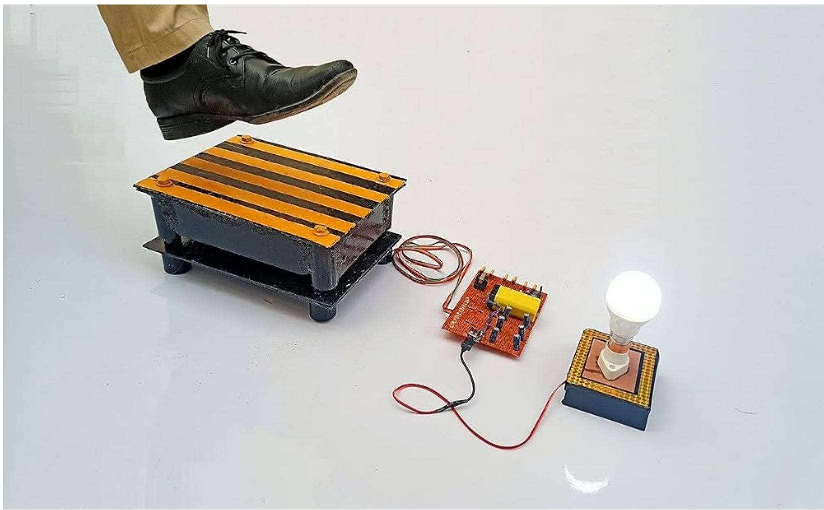

Figure : Assembly of Various Components

6.2 Mechanical Losses: Part of the applied foot force is lost in the tile, foam, frame, friction, and vibration. If the top plate is too rigid, the piezo discs do not deform enough. If it is too flexible, the system becomes unstable and energy transfer is irregular. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

6.3 Electrical Losses: Diode forward drops can consume a significant portion of low-voltage piezo output. Capacitor leakage and poor wiring joints also reduce performance. Using Schottky diodes or synchronous circuits may improve efficiency in advanced versions. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

7. Vehicle Pressure Energy Generation –Vehicle pressure systems generate electricity from the weight of moving vehicles. Heavy vehicles produce larger force, which creates higher electrical output.

12. Advantages -

- Easy installation
- Eco-friendly
- Useful in crowded places

13. Applications

- Smart highways
- Toll plazas
- Traffic signals
- Street lights

7.1 Vehicle Pressure Adaptation: For vehicle applications, the structure must be stronger, weather-resistant, and mechanically reinforced. Instead of fragile small discs directly under a tire, modular protected transducers or hybrid mechanical amplifying systems may be used. Vehicle-based systems are more complex but potentially offer higher force input.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

7.2 Speed Breaker Electricity Generation System: The provided image illustrates a speed breaker electricity generation system. This mechanism converts the kinetic energy of vehicles passing over a speed bump into electrical energy.System Components & Workflow Based on the block diagram and the 3D model, the process follows these stages:

1. **Speed Breaker Arrangement:** As a vehicle drives over the bump, its weight pushes the breaker downward.
2. **Rack & Pinion / Chain Sprocket:** This downward linear motion is converted into rotational motion using a rack and pinion gear system combined with a chain and sprocket.
3. **Flywheel:** The rotational energy is transferred to a flywheel, which helps maintain steady momentum and smooths out the intermittent power pulses.
4. **Generator:** The flywheel spins the generator (alternator), which converts the mechanical energy into electricity.

14. Storage & Output:

• Battery: Stores the generated DC power.

• Inverter: Converts DC power to AC power.

• Street Lights: The final application where the electricity is utilized.

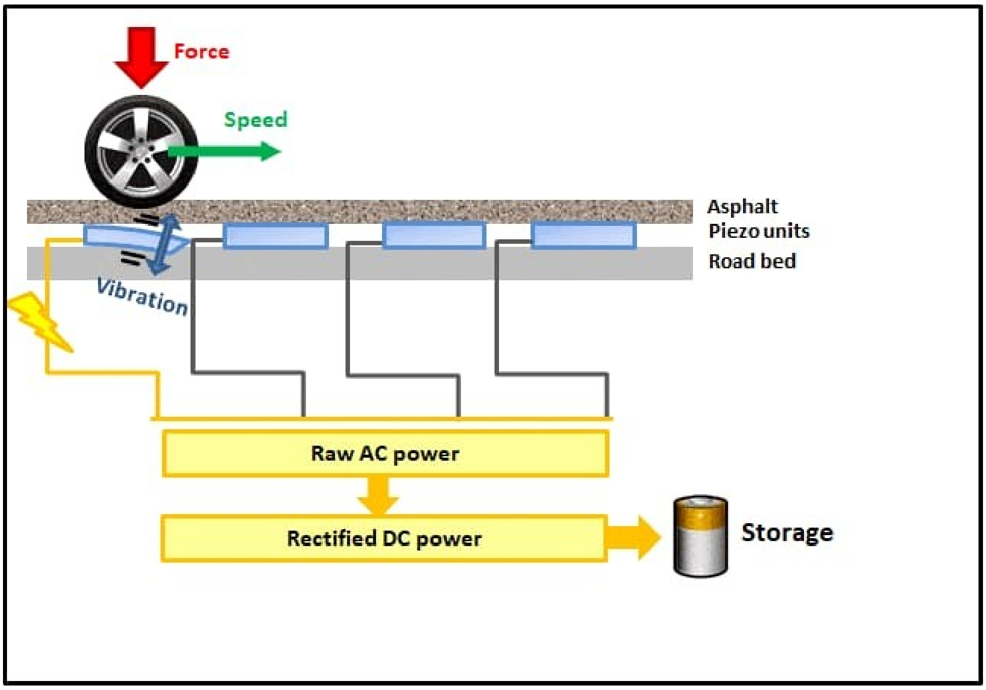

Figure: Speed Breaker Electricity Generation System

Mechanical Details: The physical assembly includes:

- **Springs:** To return the speed breaker to its original position after the vehicle passes.
- **Shaft & Freewheel:** Ensures the generator continues to rotate in one direction even as the rack moves up and down.
- **Frame:** The structural support holding the entire mechanism beneath the road surface.

The image illustrates a concept for **"Kinetic Roads",** which are designed to harness energy from vehicles.

- **Energy Generation:** These systems utilize the kinetic energy and pressure from moving vehicles, converting vibration and weight into electrical energy.
- **Applications:** The generated power can be used to run streetlights, traffic signals, and road heating systems to prevent icing in winter.
- **Technology:** While the image shows a physical speed bump, similar technologies involve piezoelectric materials embedded within the road surface itself.
- **Sustainability:** This initiative is part of efforts to create green energy solutions and reduce reliance on external power grids.

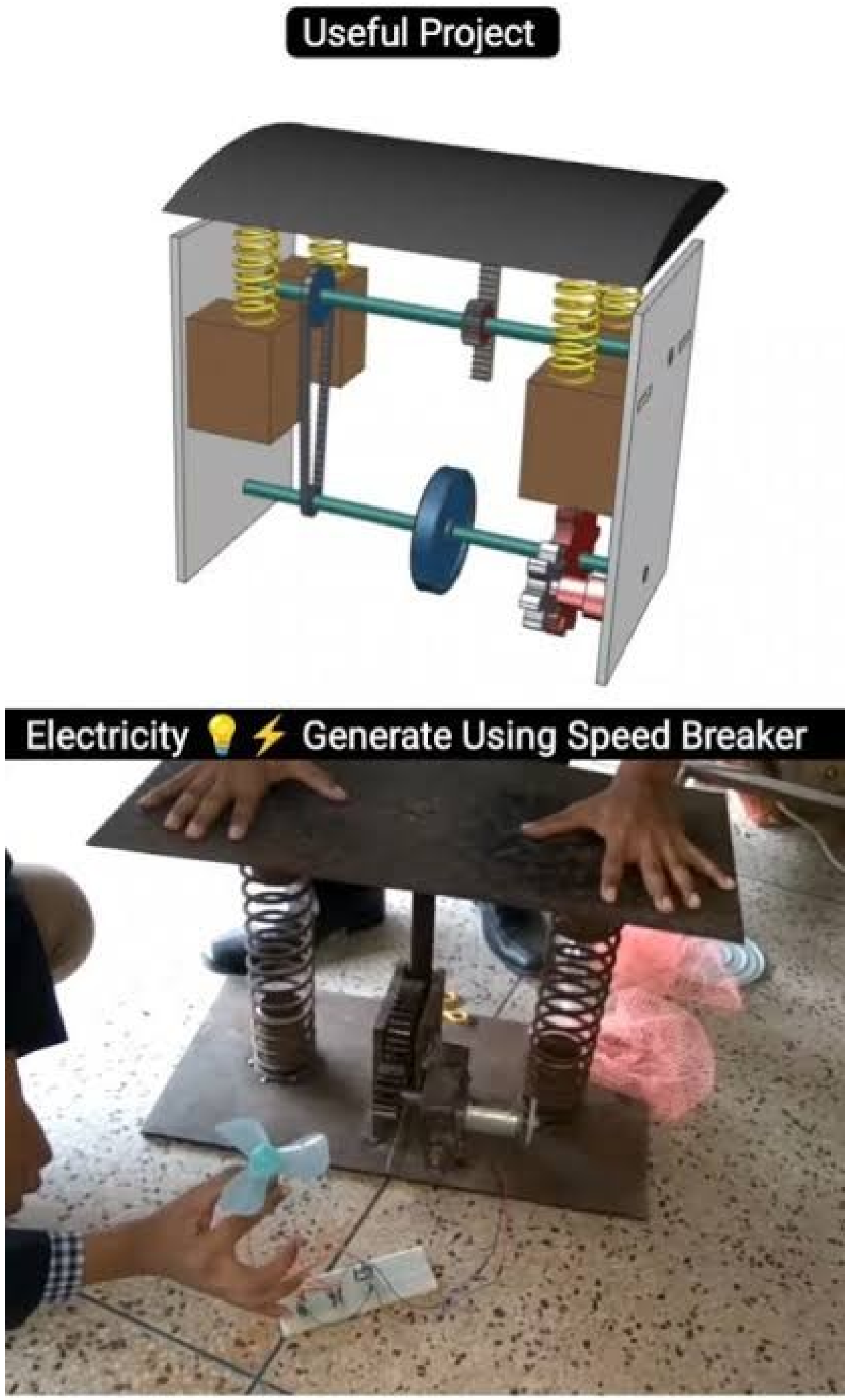

Figure: Kinetic Roads

8. Fabrication Details: The frame structure for the total unit is fabricated using L-Angle frames and ordinary frames. These frames are made of mild steel. They are held to proper dimension. are attached to form a unit with the help of welding. Then the bearings which are of standard make are kept in place with their respective shafts through them and are welded to the frame structure. The shafts are also made of mild steel. Hinges are used to move the speed breaker arrangement by welding it to the frame structure. These hinges are responsible for the movement of the speed breaker in an up and down motion.

8.1. Fabrication model showing inner parts: Wires are connected to the terminals of the DC generator and its other ends are connected to a Lead-Acid battery. Another wire is taken from these points on the battery and its other ends are connected to the positive and negative terminal of an inverter. An output wire from the inverter is sent to the light.

14.1. Materials Used:-

- Rack Mild steel
- Pinion Mild Iron
- Sprocket wheels- Mild steel
- Chain Mild steel
- Spur gears Cast Iron
- Springs Mild steel
- Shaft Mild steel
- Speed breaker Mild steel

14.2. Specifications:-

Generator - 12v DC generator

Battery - lead acid battery

Inverter - 250 w AC inverter

8.5 Fabrication Used: This classic mechanical engineering project converts the kinetic energy of passing vehicles into usable electrical energy. By changing a vertical, reciprocating push into rotational movement, the system spins a DC generator to create power.

Below is a scannable breakdown of your fabrication steps, how the system works, and the components you need.

How the Mechanism Works -

- **Vertical to Linear Motion:** When a vehicle drives over the speed breaker, the weight pushes the hinged hump downward.

- **Linear to Rotational Motion:** A mild steel rack is attached to the speed breaker hump. As the rack moves down, it meshes with a pinion (36 teeth), which converts the up-and-down motion into spinning (rotational) motion.
- **Speed Multiplication:** The sprocket and chain setup (large sprocket to small sprocket) increases the rotation speed of the bottom shaft.
- **Continuous Spin (Flywheel):** The cast iron flywheel keeps the shaft spinning smoothly even when there are momentary pauses between vehicles.
- **Electricity Generation:** The spinning shaft rotates the 12v DC generator, converting that mechanical movement into electricity.

15. Power Storage and Output -

- **Storage:** The electricity from the DC generator travels through wires into a Lead-Acid battery, which stores the power.
- **Conversion:** Because the battery produces Direct Current (DC) and many output devices require Alternating Current (AC), the power is routed through an inverter.
- **Usage:** The inverter's output supplies electricity to a connected light (such as a street light).

16. Key Fabrication Materials -

- **Frame:** Mild steel L-Angles (welded for a rigid structure).
- **Gears:** Mild steel rack and a 36-teeth pinion.
- **Transmission:** Standard bicycle chain and sprocket wheels.
- **Energy Stabilizer:** Cast-iron flywheel (machined on a lathe).
- **Electrical System:** 12v DC generator, Lead-Acid battery, and DC-to-AC inverter.

If you are looking to build or upgrade this project, there are a variety of ways to refine it.

16.1. Materials and Components Required

Hardware Components –

Components	function
Piezoelectric Sensors	Generate voltage from pressure
Breadboard	Circuit Connection
Diodes	Rectification
Capacitor	Temporary charge storage
Rechargeable battery	Energy storage
LED	Output indication
Wooden board	Pressure platform
Wires	Electrical connection
Multimeter	Voltage measurement

9.1 Description of Components: Piezoelectric discs act as transducers and form the heart of the project. A bridge rectifier converts the pulsating AC-like output into DC. Capacitors store the charge and reduce voltage ripple. The top plate ensures force transfer to the sensors, while foam or springs provide mechanical recovery after each step. LEDs are used as visible indicators of generated power. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

10. Experimental Setup : The setup should be designed so that applied force reaches the sensors efficiently without breaking them. A top plate is supported on a flexible layer, and the piezo elements are placed where

compression or bending is maximum. Wiring must be insulated and strain relieved. The output terminals are connected to measurement instruments and storage components.

The experimental setup consists of multiple piezoelectric discs connected under a wooden plate.

17. When pressure is applied:

- Voltage is generated.
- Output passes through bridge rectifier.
- DC output is stored in capacitor and battery.

18. Setup Description

1. Fix piezo sensors below wooden plate.
2. Connect sensors in parallel.
3. Connect output to bridge rectifier.
4. Connect capacitor and battery.
5. Attach LED for indication.

10.1. Methodology for Experiment: The experiment should be performed systematically. First, check single-sensor output. Then test combinations of 2, 4, 6, and 8 sensors. Apply similar stepping conditions and measure open-circuit voltage, capacitor charging voltage, and LED response. Repeat each case multiple times and record average values. A controlled and repeatable method improves credibility.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

10.2. Experimental Variables: Independent variables include applied force, number of piezo sensors, connection type, and stepping frequency. Dependent variables include output voltage, charging time, and stored energy. Controlled variables include the same tile material, same circuit, similar stepping area, and same capacitor value. Such separation is essential in scientific experimentation.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

11. Basic Theory of Energy Harvesting: Energy harvesting means collecting small amounts of ambient energy from the environment and converting it into useful electrical form. Common sources include solar light, thermal gradients, radio-frequency waves, airflow, vibration, and mechanical stress. Mechanical energy harvesting is especially important where repeated force or motion is already available. Examples include vibration in machinery, human walking, door movement, and road deformation under vehicles. The purpose of energy harvesting is not always to replace the electrical grid. In many applications, the goal is to power remote sensors, reduce battery usage, or extend system life. This project belongs to the category of mechanical-to-electrical energy conversion using piezoelectric materials.

11.1 Literature Background: Previous studies and project reports commonly identify footsteps as a practical educational source of piezoelectric energy harvesting, especially in walkways and public areas. Some reports also extend the concept to vehicle-related stress and suspension-based energy harvesting, showing that deformation under automotive loads can generate measurable electrical output, though durability and output optimization remain important challenges. Published technical material further shows that piezoelectric generators operate safely only within certain stress ranges, and stable output depends on proper mechanical loading and long-cycle reliability. These findings support the present project idea: the concept is scientifically valid, but practical output is usually small and strongly dependent on system design.

11.2. Scientific Principle: Inside a piezoelectric material, positive and negative charge centers normally balance in the unstressed state. When pressure is applied, the structure deforms and this balance changes, leading to polarization. This polarization creates a potential difference across the material. If the electrodes are connected through a load, current flows for a short duration. Because footsteps are dynamic events rather than constant pressure, the output is often pulsed AC-like electrical energy. Therefore, a rectifier is usually required to obtain DC suitable for storage. The amount of useful output depends not only on the piezo element itself but also on the mechanical mounting and the power conditioning circuit.

12. Electrical Circuit Design: The raw output from piezo discs is not directly suitable for powering loads. Therefore the circuit includes a bridge rectifier, smoothing capacitor, optional boost converter, storage element, and load. Measuring points should be provided before and after rectification. This helps compare raw sensor output with conditioned output. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

12.1 Bridge Rectifier and Filtering: A bridge rectifier made from four diodes converts bidirectional pulses into unidirectional current. Because the output is still discontinuous, a capacitor is connected across the output to smooth the voltage. The larger the capacitor, the better the smoothing, but charging becomes slower. Therefore the capacitor value should be selected according to the project objective. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

12.2. Low Power Electronics Applications: Possible loads include LEDs, LCD indicators, counters, occupancy sensors, temperature sensors, BLE beacons, and microcontroller wake-up circuits. These applications require far less energy than motors or household appliances, making them better suited to harvested micro-power. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

13. Energy Storage Section: The generated energy can be stored in an electrolytic capacitor, supercapacitor, or rechargeable cell. For demonstration, a capacitor is preferred because it shows charging behavior clearly. The stored energy can later flash an LED or run a small timer. Storage makes the output more meaningful than observing only instantaneous pulses. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

13.1 Procedure for Data Collection: Connect the multimeter across the output terminals. Apply one step and note peak voltage. Then apply 10 repeated steps and note capacitor voltage. Repeat the test for different numbers of sensors and different users or masses. Record all values in tables. Average readings should be taken to reduce random variation.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

14. Observation Table: Single Piezo: A single piezo disc may produce measurable voltage pulses but low current. The open-circuit voltage can appear surprisingly high, but the energy remains small because the charge quantity is limited. This teaches the important difference between voltage and power.

Trial	Condition	Peak Voltage (V)	Capacitor Voltage (V)	Remarks
1	Sample condition 1	____	____	Record experimentally
2	Sample condition 2	____	____	Record experimentally
3	Sample condition 3	____	____	Record experimentally
4	Sample condition 4	____	____	Record experimentally
5	Sample condition 5	____	____	Record experimentally
6	Sample condition 6	____	____	Record experimentally
7	Sample condition 7	____	____	Record experimentally

Students should fill the above table with their own measured values from the prototype. Multiple trials are required to obtain average and reliable data.

14.1. Observation Table: Multiple Piezo in Series: When piezo elements are connected in series, output voltage generally increases. However, the current capability does not improve significantly. Series connection is useful when a higher rectified voltage is needed to cross diode drops or charge a capacitor.

Trial	Condition	Peak Voltage (V)	Capacitor Voltage (V)	Remarks
1	Sample condition 1	____	____	Record experimentally
2	Sample condition 2	____	____	Record experimentally
3	Sample condition 3	____	____	Record experimentally
4	Sample condition 4	____	____	Record experimentally
5	Sample condition 5	____	____	Record experimentally
6	Sample condition 6	____	____	Record experimentally
7	Sample condition 7	____	____	Record experimentally

Students should fill the above table with their own measured values from the prototype. Multiple trials are required to obtain average and reliable data.

14.2. Observation Table: Multiple Piezo in Parallel: When piezo elements are connected in parallel, current capability improves while voltage remains closer to that of a single element. Parallel arrangements can support better charge transfer if the mechanical loading on all discs is similar. Unequal loading may reduce the benefit.

Tria	Condition	Peak Voltage	Capacitor Voltage	Remarks

l		(V)	(V)	
1	Sample condition 1	____	____	Record experimentally
2	Sample condition 2	____	____	Record experimentally
3	Sample condition 3	____	____	Record experimentally
4	Sample condition 4	____	____	Record experimentally
5	Sample condition 5	____	____	Record experimentally
6	Sample condition 6	____	____	Record experimentally
7	Sample condition 7	____	____	Record experimentally

Students should fill the above table with their own measured values from the prototype. Multiple trials are required to obtain average and reliable data.

14.3 Observation Table: Effect of Body Weight: Different users may produce different outputs depending on body mass and stepping style. A heavier load can create greater deformation and hence more charge, but only up to the safe mechanical limit of the sensors. Too much force may damage the discs or mounting structure.

Trial	**Condition**	**Peak Voltage (V)**	**Capacitor Voltage (V)**	**Remarks**
1	Sample condition 1	____	____	Record experimentally
2	Sample condition 2	____	____	Record experimentally
3	Sample condition 3	____	____	Record experimentally
4	Sample condition 4	____	____	Record experimentally
5	Sample condition 5	____	____	Record experimentally
6	Sample condition 6	____	____	Record experimentally
7	Sample condition 7	____	____	Record experimentally

Students should fill the above table with their own measured values from the prototype. Multiple trials are required to obtain average and reliable data.

14.4 . Observation Table: Repeated Footsteps: Repeated steps can charge a capacitor gradually. One isolated step may not light an LED continuously, but 20 to 50 steps may accumulate enough energy to create a visible output. This shows the importance of energy accumulation over time.

Trial	**Condition**	**Peak Voltage (V)**	**Capacitor Voltage (V)**	**Remarks**
1	Sample condition 1	____	____	Record experimentally
2	Sample condition 2	____	____	Record experimentally
3	Sample condition 3	____	____	Record experimentally
4	Sample condition 4	____	____	Record experimentally
5	Sample condition 5	____	____	Record experimentally

6	Sample condition 6	_____	_____	Record experimentally
7	Sample condition 7	_____	_____	Record experimentally

Students should fill the above table with their own measured values from the prototype. Multiple trials are required to obtain average and reliable data.

14.5. Observation Table: Capacitor Charging: Capacitor voltage increases in steps as more footfalls occur. At first the charging is relatively fast, but as the capacitor voltage rises, the rate slows. This behavior can be explained through charge accumulation and increasing opposing voltage across the capacitor.

Trial	Condition	Peak Voltage (V)	Capacitor Voltage (V)	Remarks
1	Sample condition 1	_____	_____	Record experimentally
2	Sample condition 2	_____	_____	Record experimentally
3	Sample condition 3	_____	_____	Record experimentally
4	Sample condition 4	_____	_____	Record experimentally
5	Sample condition 5	_____	_____	Record experimentally
6	Sample condition 6	_____	_____	Record experimentally
7	Sample condition 7	_____	_____	Record experimentally

Students should fill the above table with their own measured values from the prototype. Multiple trials are required to obtain average and reliable data.

15. Sample Calculations: If a capacitor of 1000 microfarads charges to 5 volts, the stored energy is E = 1/2 C V^2. Substituting C = 1000 × 10^-6 F and V = 5 V gives E = 0.0125 J. This amount is small, but enough to demonstrate the concept. Repetition and optimization can improve usable output.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

Item	Sample Value	Notes
Piezo discs	10–20 pieces	As per design
Rectifier	4 diodes	Bridge type
Capacitor	470–2200 uF	Storage element
LED load	1 or more	Demonstration

16. Formula Sheet: Useful formulas include: Energy in capacitor $E = 1/2\ C\ V^2$; Electrical power P = VI; Charge Q = CV; Efficiency = output energy / input mechanical energy × 100. These formulas help convert raw measurements into meaningful performance indicators. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

Item	Sample Value	Notes
Piezo discs	10–20 pieces	As per design
Rectifier	4 diodes	Bridge type
Capacitor	470–2200 uF	Storage element
LED load	1 or more	Demonstration

16.1. Cost Analysis: A student prototype can be prepared at relatively low cost using locally available components. Basic parts include piezo discs, diodes, capacitor, wood or acrylic plate, wires, LEDs, and support materials. Advanced monitoring raises cost but improves data quality. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

Item	Sample Value	Notes
Piezo discs	10–20 pieces	As per design
Rectifier	4 diodes	Bridge type
Capacitor	470–2200 uF	Storage element
LED load	1 or more	Demonstration

16.2. Data Interpretation: A high open-circuit voltage alone does not mean high power generation. Real usefulness depends on current, energy storage, and load compatibility. Therefore output should always be interpreted in terms of both voltage and stored energy. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

17. Graph 1 Discussion: Graph 1 may show number of sensors versus output voltage. Normally the curve rises with more sensors, but the increase may not be perfectly linear because loading is not equally distributed. Mechanical design strongly influences this graph.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.1. Graph 2 Discussion

Graph 2 may show number of footsteps versus capacitor voltage. The graph usually rises quickly at first and then gradually slows. This reflects the natural charging behavior of a capacitor and finite harvested energy per step.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.2. Graph 3 Discussion

Graph 3 may compare series and parallel arrangements. Series often gives higher peak voltage, while parallel gives better charge delivery. The best final design may combine groups of series-connected discs in parallel banks.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18. Efficiency Considerations: Overall efficiency is low because not all mechanical energy reaches the transducers, and not all electrical output reaches the load. Mechanical damping, poor contact, diode losses, leakage, and mismatch reduce performance. Therefore optimization is essential. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.3. Role of Sensor Arrangement

The physical arrangement of piezo discs matters as much as electrical connection. Sensors should be placed where bending stress is maximum. Uniform pressure distribution leads to better combined output. Poor arrangement wastes force on inactive regions.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.4. Force Distribution Issues

A single footstep does not apply uniform pressure over the entire tile. Heel and toe regions may experience different forces. Therefore some sensors may contribute more than others. This explains why experimental results often vary between trials.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

19. Smart City Relevance: In smart city infrastructure, many wireless sensor nodes require only small power. Piezoelectric floor tiles can contribute to localized energy support or event-triggered sensing systems. This makes the technology relevant even when absolute power is modest.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.5. Applications in Public Places

Such systems may be installed in railway stations, malls, airports, schools, or exhibition halls to power decorative LEDs, counters, or awareness displays. They are especially useful where human movement is already continuous. The educational visibility of renewable energy is also valuable.This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.6. Use in Transportation Zones

At toll plazas, parking gates, and traffic calming structures, repeated vehicle loads offer another opportunity for harvesting. Research on tire and automotive deformation indicates that power can be generated from such stress, though practical design remains challenging .

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

18.7. Environmental Impact

The system helps promote renewable awareness by using otherwise wasted motion. It does not produce pollution during operation. However, disposal of electronic components and piezo ceramics must be handled responsibly. Sustainability should include both usage and material management. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

19. Advantages of the System

The system uses wasted energy, encourages renewable thinking, can be built as a compact model, and demonstrates interdisciplinary learning. It works without fuel and can operate in locations where footsteps are abundant. It is also an attractive awareness project for science exhibitions. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

19.1. Precautions During Fabrication

Do not apply excessive point load directly on bare piezo discs. Use cushioning and alignment supports. Check polarity, avoid short circuits, and ensure firm but not over-tight mounting. Test the circuit before allowing repeated stepping.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

19.2. Improvements and Optimization

Performance can be improved by better force concentration mechanisms, optimized series-parallel networks, Schottky rectifiers, supercapacitors, and stronger packaging. Mechanical amplifiers such as levers or springs may increase useful deformation. Data logging can also improve analysis quality.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

21. Future Scope: Future versions may integrate IoT sensors, wireless transmission, occupancy analytics, and hybrid systems combining solar plus footstep harvesting. In vehicle systems, energy harvesting roads or speed breakers may be explored experimentally, though material strength and economics remain critical. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

19.3. Educational Value

This project is excellent for B.Sc. students because it demonstrates direct application of physics concepts, circuits, measurements, and engineering design. It encourages observation, data analysis, and practical problem-solving. It also provides a modern sustainability-oriented science topic. This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

22. Result Summary: he experimental concept successfully demonstrates that mechanical stress can produce measurable electrical energy through piezoelectric transducers. Multiple sensors, proper rectification, and storage improve usable output. The prototype is best suited for demonstration and low-power applications rather than large-scale power supply.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

23. Conclusion: Mechanical stress based power generation is scientifically valid and practically demonstrable. The project shows that footsteps and pressure can be converted into electrical energy, stored, and applied to small loads. Experimental analysis confirms that force level, number of sensors, arrangement, and circuit conditioning are all important. The system is promising for educational prototypes and micro-power applications, but large-scale implementation requires better materials, stronger mechanics, and more efficient electronics.

This section should be explained in the final submission with the help of your own diagram, labelled circuit, and teacher-approved observations. You can also attach hand-drawn graphs or photographs of the model to strengthen the project report.

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